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The U.S. Army uses a combat simulator, Janus(A), to simulate high-tech ground battle exercises. The algorithms used to represent battlefield behavior and to generate battle scenarios must be calibrated by well-trained, combat-experienced technicians. The calibration is time-consuming and subject to human errors. A Single Exercise Analysis System (SEAS) is under development for automating and improving the battle scenario generation process for Janus(A). A neural network based model has been proposed to support the route determination process within SEAS. The purpose of this thesis is to (1) determine the best neural network architecture for determining tank routes and (2) develop a prototype for generating these routes.

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The Use of Neural Networks for Determining Tank Routes

by

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

The U.S. Army uses a combat simulator, Janus(A), to simulate high-tech ground battle exercises. The algorithms used to represent battlefield behavior and to generate battle scenarios must be calibrated by well-trained, combat-experienced technicians. The calibration is time-consuming and subject to human errors. A Single Exercise Analysis System (SEAS) is under development for automating and improving the battle scenario generation process for Janus(A). A neural network based model has been proposed to support the route determination process within SEAS. The purpose of this thesis is to (1) determine the best neural network architecture for determining tank routes and (2) develop a prototype for generating these routes.

C.1

TABLE OF CONTENTS

I. INTRODUCTION

A. PURPOSE

A neural network based route generation process is proposed to improve the performance of scenario generation for the Army's Janus(A) combat model. More specifically, when the quality of data permits, this process will automate processes currently performed manually. Eventually, a finished version of this prototype will be integrated with a Single Exercise Analysis System (SEAS) under development.

There are two primary purposes for this thesis. First, to determine the best neural network architecture for determining tank routes. Second, to develop a prototype for generating these routes.

B. BACKGROUND

The U.S. Army utilizes Janus(A), a combat simulator, to emulate the complex reality of high-tech ground battles or battle exercises. This model is equipped with algorithms that represent battlefield behavior in typical combat situations. This combat simulator provides calibration mechanisms for adjusting simulation parameters to allow for various battle contexts that might occur. This calibration must be performed by an analyst who is well-trained and experienced in combat. In addition, he must be familiar with the combat simulator.

This calibration is time-consuming, subject to human errors and may not be complete (Tversky and Kahneman, 1974).

A *neural network algorithm* is proposed to perform the task of generating tank routes for training and evaluation and training. This is proposed to seek a behavioral rather than analytical representation of the tanks in a battlefield. It is also an effort toward using machine learning techniques for analyzing actual combat behaviors. This neural network will capture actual successful routes of tank commanders who were confronted with evolving combat simulations. This algorithm will then be used to predict the movement of a tank given its initial position.

C. ORGANIZATION OF THE THESIS

The thesis is organized as follows. Chapter II provides an overview of the route determination process and of using neural networks for route determination. Chapter III describes the search for the best network architecture for route generation and the results of the search. Chapter IV presents the prototype for route determination. The summary of findings and recommendations for further research is provided in Chapter V.

II. OVERVIEW OF USING NEURAL NETWORKS FOR ROUTE DETERMINATION

A. TANK ROUTE DETERMINATION PROBLEM

According to the U.S. Army doctrine (USA-FM17-15, 1987), a tank commander should determine his route based on the following major principles:

- Follow the route determined by the concept of operation.
- Employ unit movement techniques and drills to balance speed with likelihood of enemy contact.
- Use the terrain and natural or man-made cover and concealment to mask his weapon system from enemy observation.

It is expected that trained troops will follow as close as possible the concepts of engagement laid out by high-level command. However, factors on the battlefield may require significant departures from company commander's intent and execution plan. Factors governing a tank commander's movement include his position, route, enemy's position, and his vulnerability.

Route determination is a dynamic, real-time reasoning process with incomplete and possibly inexact information. As a battle unfolds, each time slice can be perceived by the tank commander as a life-threatening crisis that forces him to reevaluate his next movement. (Bui et al., 1992)

B. OVERVIEW OF ROUTE DETERMINATION TECHNIQUES

As a decision problem, there are at least three approaches or techniques that can be used to determine routes. These are a mathematical model approach, a heuristic approach and a *data inductive approach.*

A mathematical model approach would attempt to consider all relevant factors that lead to the determination of a route. Once these factors are determined and required data gathered, models would be developed for determining routes.

A heuristic approach would try to harness the knowledge of experts. In our case, an expert platoon commander's knowledge would form the basis of an automated expert system that could be used to determine routes. This requires gathering an expert's expertise in some way and then modeling and coding this knowledge. The resulting expert system could theoretically be used to determine tank routes. Such expert systems have been applied in the field of medical science, for example. These systems support medical personnel decision making.

The data inductive approach conjectures that, in some complex situations such as the route determination process, it would be impossible to model all direct causal relationships due to incomplete, uncertain and dynamic information. To circumvent the difficulty in applying analytical reasoning using quantitative algorithms, the inductive approach hypothesizes that there is a lot to learn from those tanks

that successfully make it though to their planned destination. Neural networks are the form of inductive approach we have chosen as the subject of this thesis.

C. USING NEURAL NETWORKS FOR ROUTE DETERMINATION

1. A Brief Description of Neural Networks

A neural network is a system consisting of several simple, highly interconnected homogeneous processing units called *neurons* (Figure 1). Each neuron is a simple computation device that continuously reacts to external inputs. Typically, a neuron receives input signals from other neurons, aggregates these signals based on an input function, and generates an output signal based on an output function or transfer function. A weighted directed graph represents the interconnection of the neurons. Nodes represent neurons and links represent connections. The weight assigned to the link between two neurons represents the relative importance of that link.

The crucial problem in training neural networks is determining a set of weights assigned to the connections that best maps all input units to their corresponding output units. In other words, the learning process can be seen as a non-linear optimization problem that minimizes output differences. The *back-error propagation* technique is probably the most widely used algorithm for minimizing the output differences. (Bui et al., 1992)

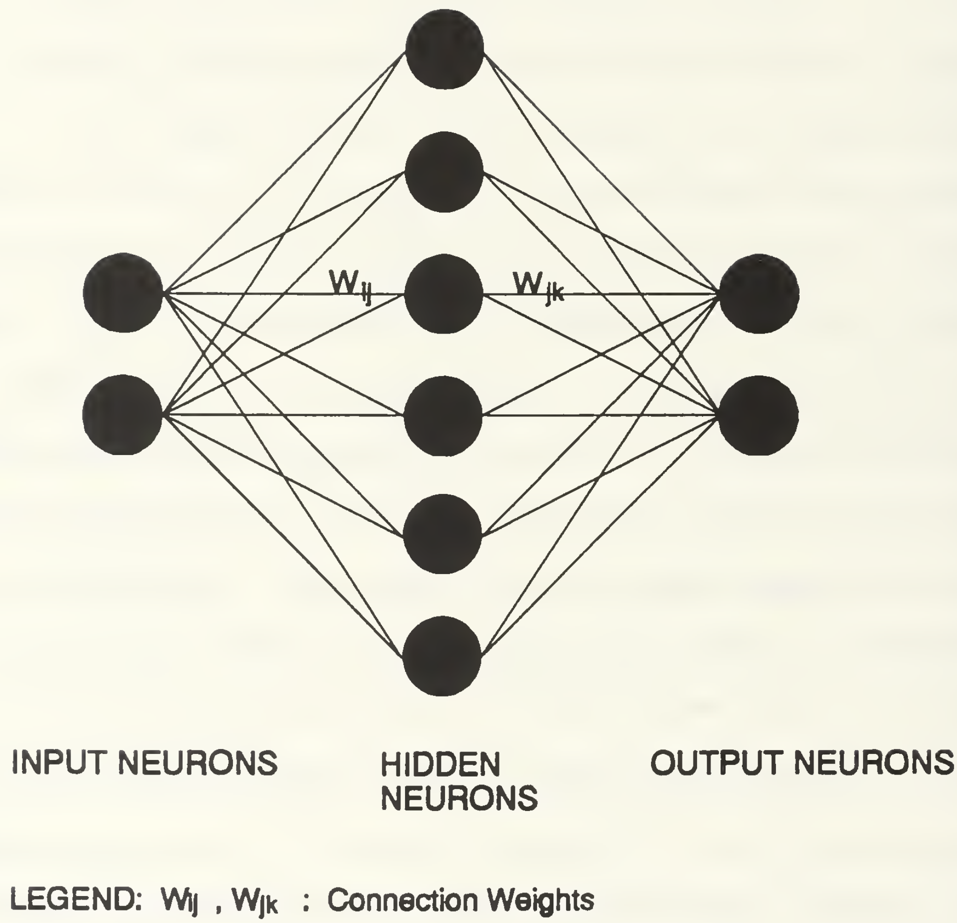


Figure 1. Neural Network Architecture

The back-error propagation technique iteratively assigns weights to connections, computes the errors between outputs and target outputs, propagates this error information back, layer by layer, from the output units to the input units, and adjusts the weights until errors are minimized. The back-error propagation technique does not guarantee an optimal solution. However, various experiments reported by Rumelhart et al. (1986) and by other researchers (Maren et al., 1990; Freeman, 1991) suggest that the algorithm provides solutions that are close to the optimal ones.

2. Advantages of using Neural Networks for Route Determination

As stated previously, the idea of using neural networks for route determination is based on the hypothesis that there is a lot to learn from those tanks that successfully made it through to their planned destination. A neural network trained to actual routes should be able to produce routes that simulate the dynamic movements of actual tank routes. These routes are derived without any detailed knowledge of how the actual routes used for training had been chosen.

3. An Example

After a battle exercise is conducted at the National Training Center, Ft. Irwin, those tanks that reached their destination are considered successful. For this exercise,

their mission was to reach a destination located approximately 9 kilometers North-East of their initial position. As these tanks moved toward their goal they would make contact with the opposing force. Nineteen tanks were successful and their routes were used to train the network model.

Forty-two coordinates, taken at five-minute intervals, represent the route of each tank. Each route begins with a point of departure and the destination point. The coordinates are x and y coordinates on the training area grid.

After training the network model, it can be used for generating routes from any feasible start coordinate. For example, an x coordinate of 43900 and a y coordinate of 96225 may be used as input to the model. The model will generate a coordinate, such as 44250, 98475, that it predicts is the next coordinate in the route. This coordinate will be used as input and another coordinate will be generated. Eventually, an entire route will be generated in this manner.

D. ISSUES RELATED TO USING NEURAL NETWORKS

1. Architecture

A neural network architecture refers to how the neurons are connected to each other and what kind of neurons they are. Typical neural networks are designed in *layers* of neurons. Each layer is a group of neurons that share a functional feature. The network used for route determination has three layers. The first layer, the *input layer*, has the

task of taking in the route data, in our case this is a tank position. The second layer, the *hidden neuron layer*, uses the output from the first layer to calculate its output to the third layer. The third layer, or *output layer*, has the task of producing an output; the next tank position. Figure 2 illustrates how a neural network architecture for determining tank routes might appear graphically.

Part of the task of designing the network architecture is determining the number of neurons included in each layer. The data available for successful tank routes include: the tank designation (unit number), time of position (every 5 minutes), the x and y coordinates of the tank and the next x and y coordinates of the tank (see Appendix A for a complete printout of the data). From this data it is necessary to decide which data is significant for the network. Table 1 presents an example of the data available for this research.

TABLE 1. EXAMPLE OF RESEARCH DATA

Time	Unit No.	X Coord.	Y Coord.	Next X Coord.	Next Y Coord.
60	42	43900	96225	44250	98475
65	42	44250	98475	45788	98500

Since we desire to produce a route that is a series of positions, the network needs the x and y coordinate data. The network does not need to know tank designations so that data is not used as an input.

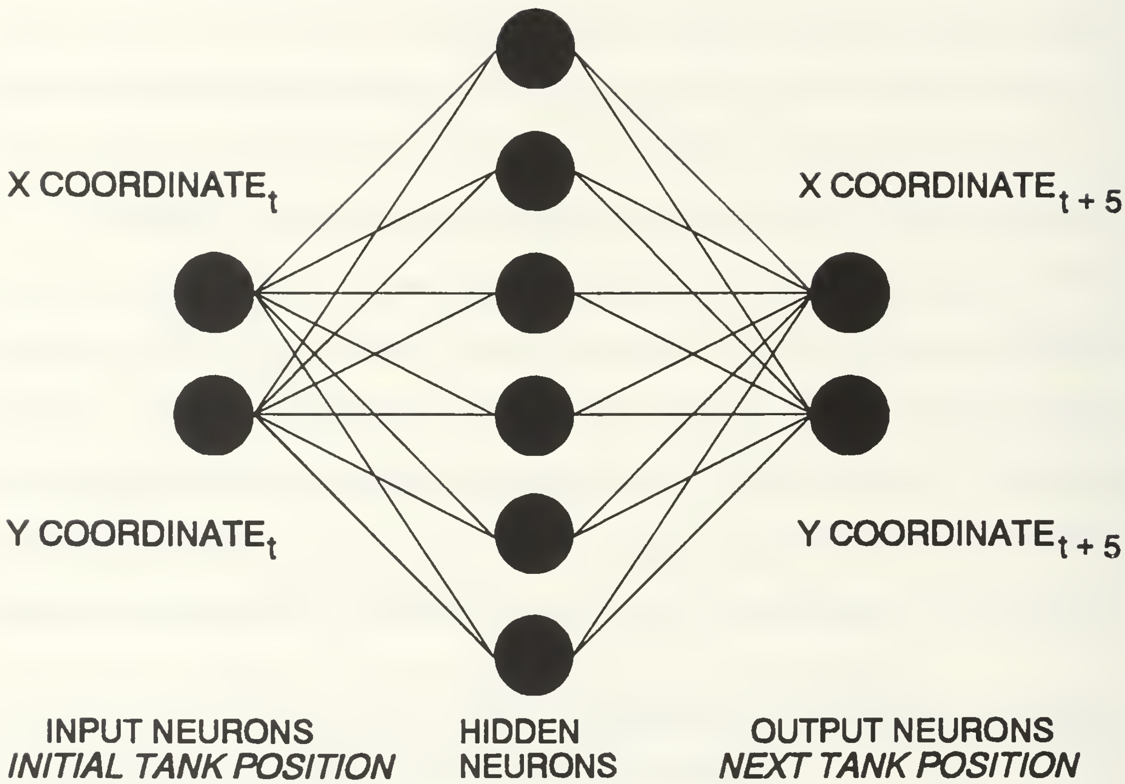


Figure 2. Neural Network Architecture for Tank Routes

When a network trains, it looks at the x and y coordinates and predicts the next x and y coordinates. Since the next x and y coordinates are 5 minutes into the future, that fact can be considered implicit. Because time is implicit in the coordinate data, it is not necessary to include time explicitly as an input to the network. This narrows the inputs to the neural network to the x and y coordinates. The input layer will have two neurons, one representing the x coordinate and one representing the y coordinate.

We want the network to predict the next x and y coordinates when given a current x and y coordinate. Therefore, the output layer will consist of two neurons representing these coordinates.

It is not as simple to determine the number of neurons in the second, hidden, layer. Because hidden neurons are necessary for the network to perform its calculations, having too few neurons in the hidden layer will cause the network not to train at all. Because increasing the neurons adds to the complexity, too many neurons may mean slower training and running (California Scientific Software, 1990). California Scientific Software, the maker of our neural network tool, BrainMaker, suggests using the average of the input and output neurons as the number of hidden neurons. If this number is less than 25, they suggest some undetermined number more than the average. They suggest that complex problems such as

problems with hundreds of facts may require more hidden neurons while straightforward or linear problems tend to require fewer. Our problem is both straight forward (given a coordinate produce the next coordinate) and has hundreds of facts (42 coordinates in an average route and a set of 19 routes). Determining the optimum number of neurons is a major portion of the research for this thesis.

We added network *training percentage* to what is commonly considered the architecture of the neural network. Training percentage refers to the number of predictions a network must get correct to complete training. When training, the x and y coordinates are the inputs and the next x and y coordinates are the *output patterns* with which the network will compare its predictions. The network considers its prediction correct when it falls within the *training tolerance* of .100 (10 percent). For example, a network will consider its prediction correct if it predicts 45000 - 95000 (x and y coordinates) and the output patterns are 49400 - 95500. We quickly discovered that it is not possible to train our networks to 100 percent.

In a set of training data (also called training facts) there may be some data that exhibit unusual patterns. For example, consider that an entire platoon is progressing over the terrain but one tank has a problem and stops for 20 minutes. That only one tank is not progressing for some period will not make sense to the network. When the tank

recovers and proceeds to catch up at a rapid pace, the network may not understand that behavior. The network may be unable to predict the next x and y coordinates for the tank during these periods since its behavior does not correlate with that of other tanks. Since such situations may not make sense to the training program it may not be possible to train this network to 100 percent. In fact, it is not possible to train our network to 100 percent given the route data used during our research. We needed to determine what network training percentage would allow the network to train and not degrade the network's prediction accuracy.

2. Accuracy

Initially, accuracy simply seems to mean "How close are predicted x and y coordinates to the actual x and y coordinates?". However, we found that any of the networks that train, despite the number of neurons, very accurately predicted next x and y coordinates when presented with an actual x and y coordinate. This makes sense because, to successfully train, a network must predict the next x and y coordinate to within a 10 percent tolerance of the output pattern. Therefore, we expanded accuracy to mean "How close to the generic, or average tank route, is a predicted tank route?" In other words, we give a network start coordinate and the network produces the next coordinate. We then give the network this coordinate and it produces the next

coordinate, and so on until the network will no longer produce a different coordinate. We then compare this series of coordinates (which comprise a route) to the generic (average) tank route to determine how closely the predicted route follows the average route.

Initially, our basis for judging the routes consisted of whether the route generally followed the path of the average route. Eventually, the *number of coordinates* in the route (representing the average speed of advance) became an additional criterion.

3. Ability to Handle Unexpected Start Positions

Also included in the testing was how the network handled *unexpected start positions*. These include such as those located in terrain that is not traversable by tanks. Would the network try to recover by proceeding to possible positions or would it just be unable to predict a route? Impossible start positions are primarily a theoretical problem since the intended eventual uses of the proposed route prediction system will have no reason to propose an impossible start position. Yet, a somewhat unexpected start position may be possible and the ability of the network to handle this is important.

III. SEARCHING FOR AN APPROPRIATE NETWORK ARCHITECTURE

A. METHODOLOGY

1. Changing the Number of Hidden Neurons

As stated previously, the makers of BrainMaker recommend the average of the input and output neurons as the number of hidden neurons unless this number is less than 25. The average is two and, although significantly less than twenty-five, we used two hidden neurons as the start. From that we decided to try 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90 and 100 or until it was obvious that increasing the number of hidden neurons was not going to increase the accuracy of the network. These choices were arbitrary, but incrementally representative, since we felt that increasing hidden neurons by 1 until 100 would be prohibitively time consuming and unnecessary. If it appeared that using 20 hidden neurons produced better routes than those produced with 15 and 25 hidden neurons then we would try varying hidden neurons around 20 to determine the optimum number. Eventually, we did train some networks using different numbers of hidden neurons not on our initial list.

2. Testing the Accuracy of Trained Networks

Initially, we put the network predicted coordinates and the output patterns into a spreadsheet and determined the average of the differences between them. We had hoped that the best network would have the smallest average differences. Although there were ranges from an average of 4 yards difference to 244 yards difference, these are not significant when talking about numbers such as 33,000 to 120,000. Also, the larger differences did not suggest any sort of trend. In other words, we found that using 20 hidden neurons produced average differences of 4 yards and using 70 hidden neurons produced average differences of 244 yards suggesting that networks with fewer hidden neurons produce more accurate predictions. On the other hand, we found that using 60 hidden produced differences of 13 yards and using 15 hidden produced differences of 121 yards which suggests that networks using more hidden neurons produce better predictions. Obviously, this method of evaluation is ineffective and probably meaningless (as discussed earlier).

We determined that evaluating the network performance visually (by comparing graphs of predicted routes with graphs of actual average routes) was the best method. Since we want routes that are feasible and generally reflect the behavior of successful routes, this method provides us with the means to evaluate these characteristics.

We used a generic tank route (Figure 3) for comparison. This route consists of coordinates that are the average of the position of the tanks in the training data at each particular time. For example, the first coordinate is an average of each tank's position at time 0 and represents the average start coordinate. The terrain (Figure 4) of the training area is such that some areas are inaccessible for the tanks. We used this graph to determine if generated routes avoided these areas as well.

We generated routes from each trained network from the generic route's average start coordinate (34135 - 97327) and visually compared them to the generic route. We visually compared the generic and generated routes to find how much they resembled each other. We also verified that the generated routes avoided the inaccessible terrain.

3. Training Time

We expected the training time to increase as we increased the number hidden neurons. We felt that the time it takes to train a network would become an important factor as we increased the number of hidden neurons. We felt there might be a point where increasing the hidden neurons (and, theoretically, the training time) might not increase the accuracy of the network enough to justify the increase in training time. Therefore, we considered training time while evaluating networks.

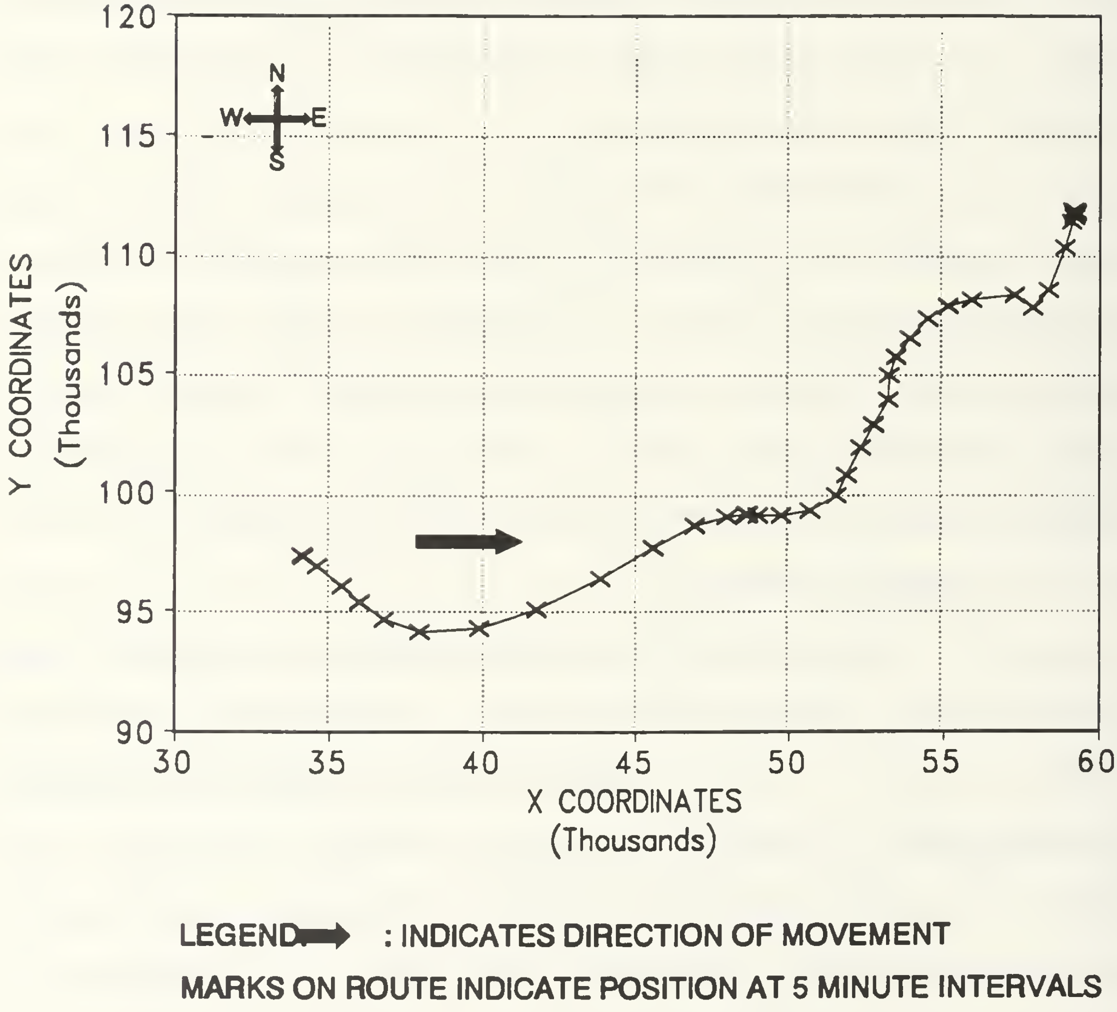
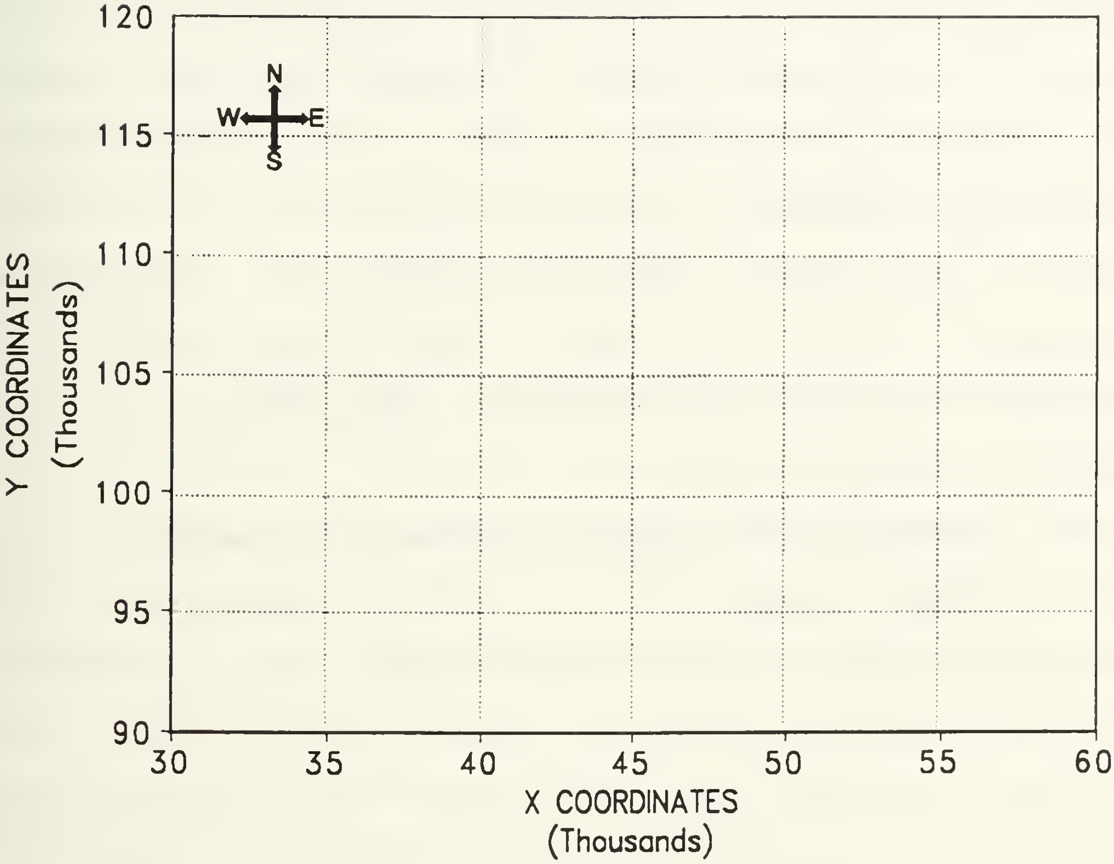


Figure 3. Generic Tank Route (Average of Original Routes)



LEGEND ▭ **: IMPASSABLE TERRAIN**

Figure 4. Terrain of Ft. Irwin Training Area

4. Unexpected Start Positions

Once we narrowed the networks down to the best three, we further evaluated them with unexpected start positions. We felt that it be the final factor in determining the "best" network architecture for predicting tank routes.

We chose three test positions. The first, 40000 - 105000, is within the vicinity of the destination, but south of any of the original routes. The second two, 42000 -110000 and 57000 - 102000, are located within hilly terrain considered impassable. We chose these points to evaluate whether the network might "recognize" this terrain as impassable and try to take a quick route to familiar territory, proceed directly to the destination area, or be unable to produce a route.

5. Summary of Training and Evaluation Procedure

It was evident that it would be prohibitively time consuming to try to train every network while varying the training percentages from 100 percent to 90 percent (for example). The first step was to find a test percentage that would allow the network to train and to train in a reasonable period without noticeably depreciating the performance. In view of the possible eventual use of a route prediction system, we considered 5 hours to be the maximum amount of time to be reasonable and hoped to get training times to within an hour. To do this, we decided to use a test network with 10

hidden neurons and to train and evaluate it (not in detail) when trained at varying training percentages.

As expected, at 100 percent the network would not train at all. Again at 99 and 98 percent, the network would not train within 5 hours. At 97 and 96 percent, training time dropped to between 1 and 2 hours. At 95 percent, training took 22 minutes and 50 seconds and training time took much less as we lowered the training percentage. There were almost no differences in the routes produced by the networks trained to 97, 96 and 95 percents. Networks trained to percentages less than 95 percent produced routes which differed noticeably.

It seems safe to assume that networks trained to a higher percentage should be more accurate. We also believe that a time of less than 30 minutes would be very acceptable for our purposes (in fact, training time will drop on faster hardware). Since there was a perceptible difference between those networks trained to less than 95 percent and those trained to 95 percent and above, we decided to train our networks to 95 percent for this research.

Once we established our training percentage, we proceeded to train networks with the various numbers of hidden neurons described previously. After completion of training, we evaluated the attributes of training time, accuracy and handling of unexpected start points as described in the

previous sections. Figure 5 graphically illustrates the evaluation process.

B. RESULTS

1. Changing the Number of Hidden Neurons

Networks were trained with the following numbers of hidden neurons: 2, 4, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90 and 100. After evaluating each network, we trained networks using 7, 9, and 11 hidden neurons to fine tune the analysis.

2. Testing the Accuracy of Trained Networks

We eliminated several networks after visually comparing the routes they produced. Some networks could not produce a complete route even when started with the average start coordinate. For example, the networks using 2 and 15 hidden neurons both failed after generating 6 to 10 coordinates of a route (Figures 6 and 7). Some networks produced routes that behaved like the successful tanks only in a very broad way, meaning that they generally started south-west like the generic route and eventually ended near the generic route's end coordinate. The route generated by the network with 20 hidden neurons (Figure 8) is an example. Some networks (like the network with 25 hidden neurons) produced routes that appeared to behave quite differently from the generic route although generally ending near the generic end coordinate (Figure 9).

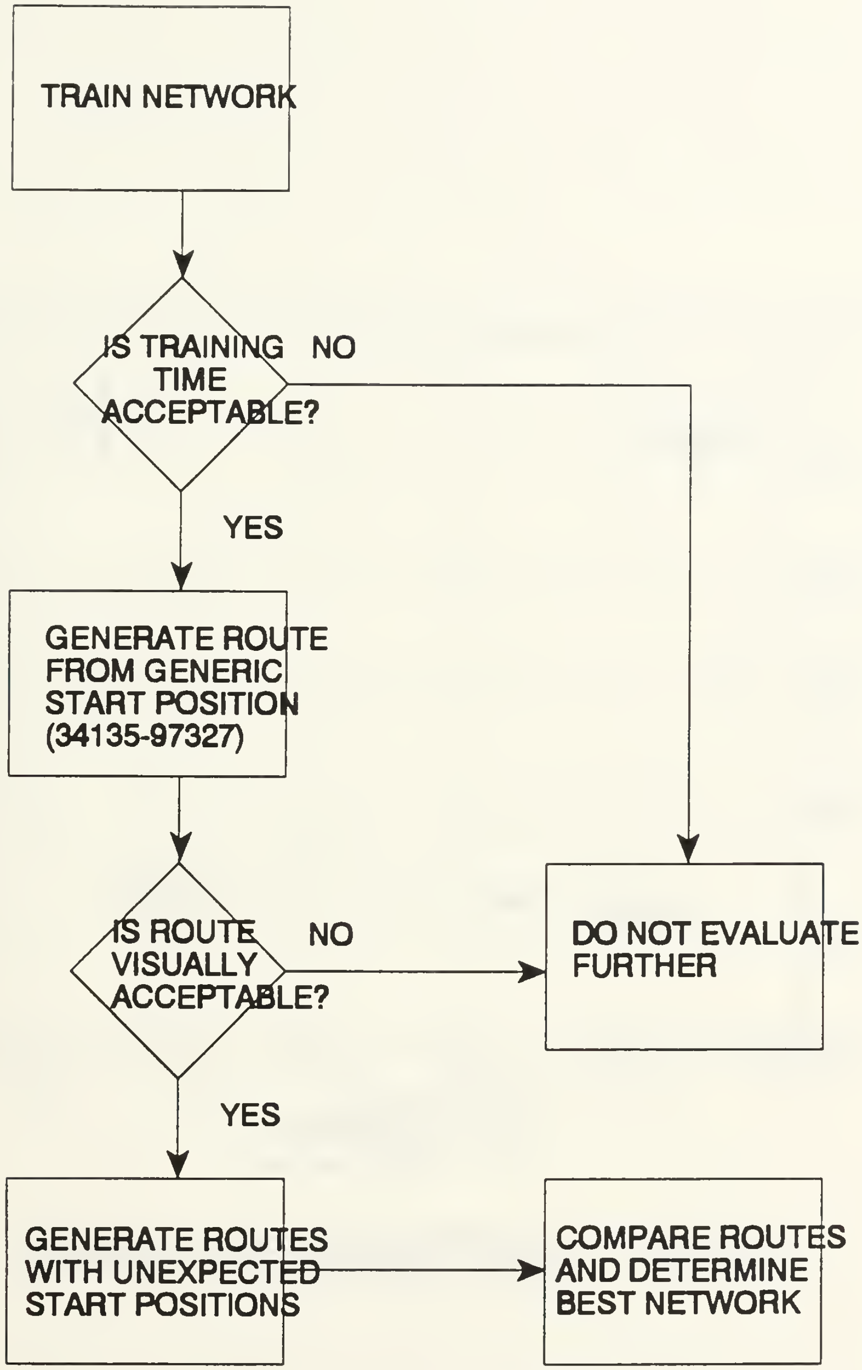


Figure 5. Diagram of Evaluation Process

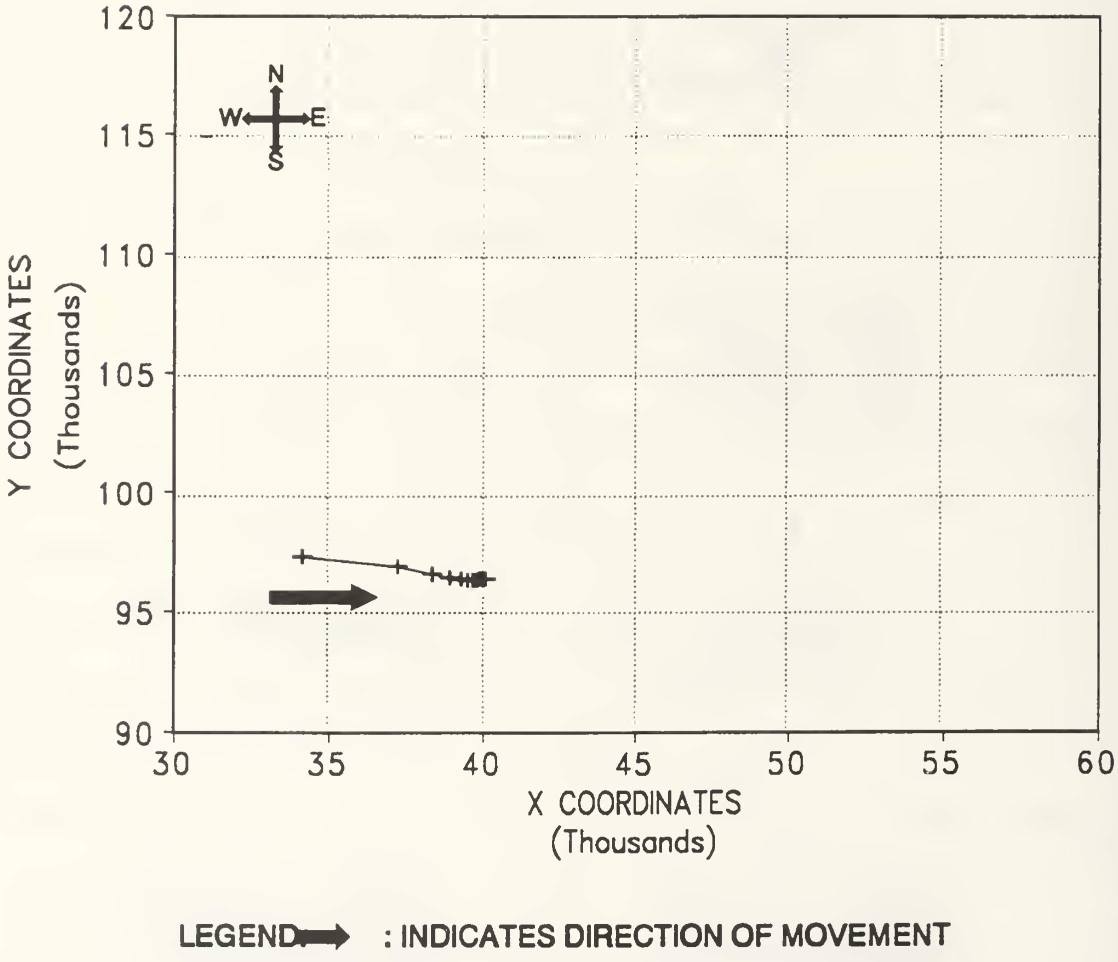


Figure 6. Route Generated by Network with 2 Hidden Neurons

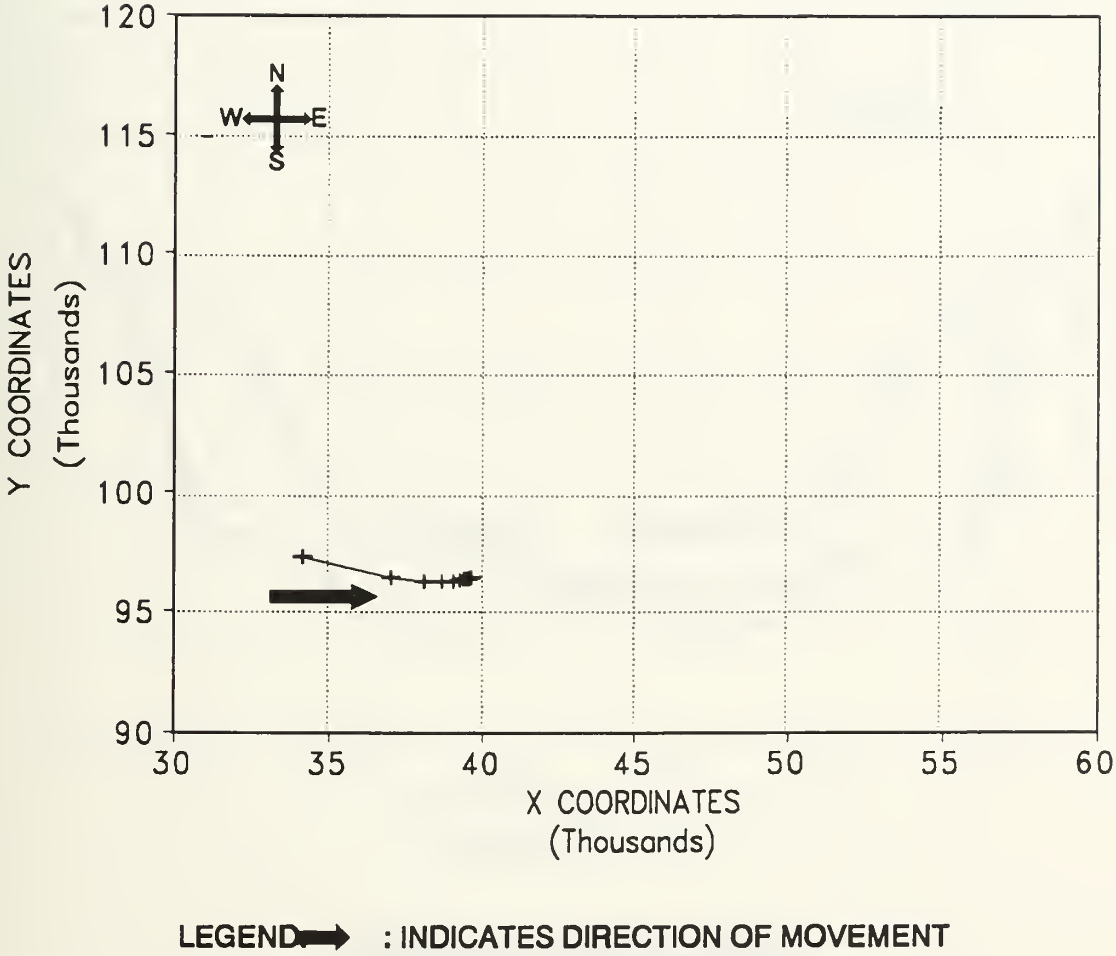


Figure 7. Route Generated by Network with 15 Hidden Neurons

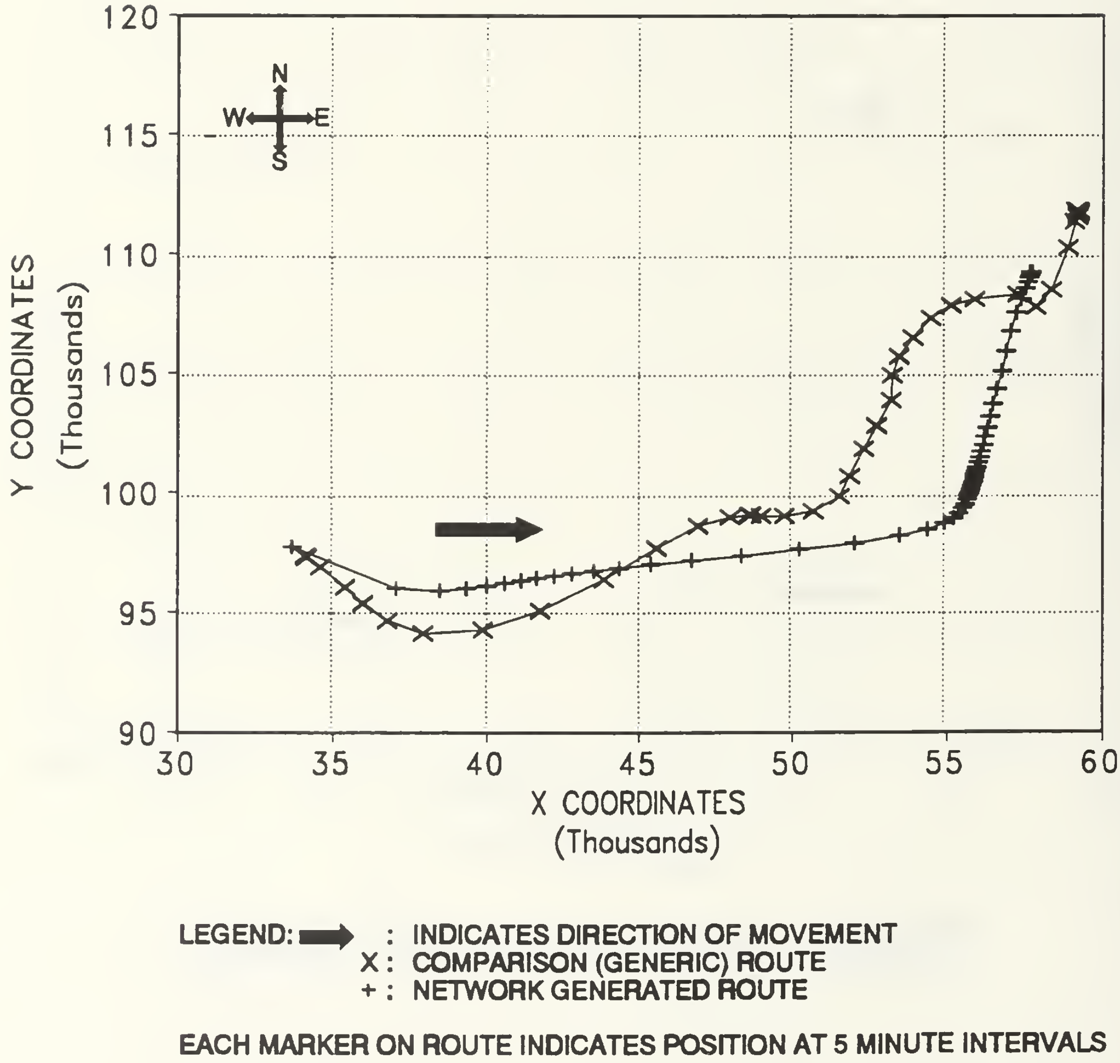


Figure 8. Route Generated by Network with 20 Hidden Neurons

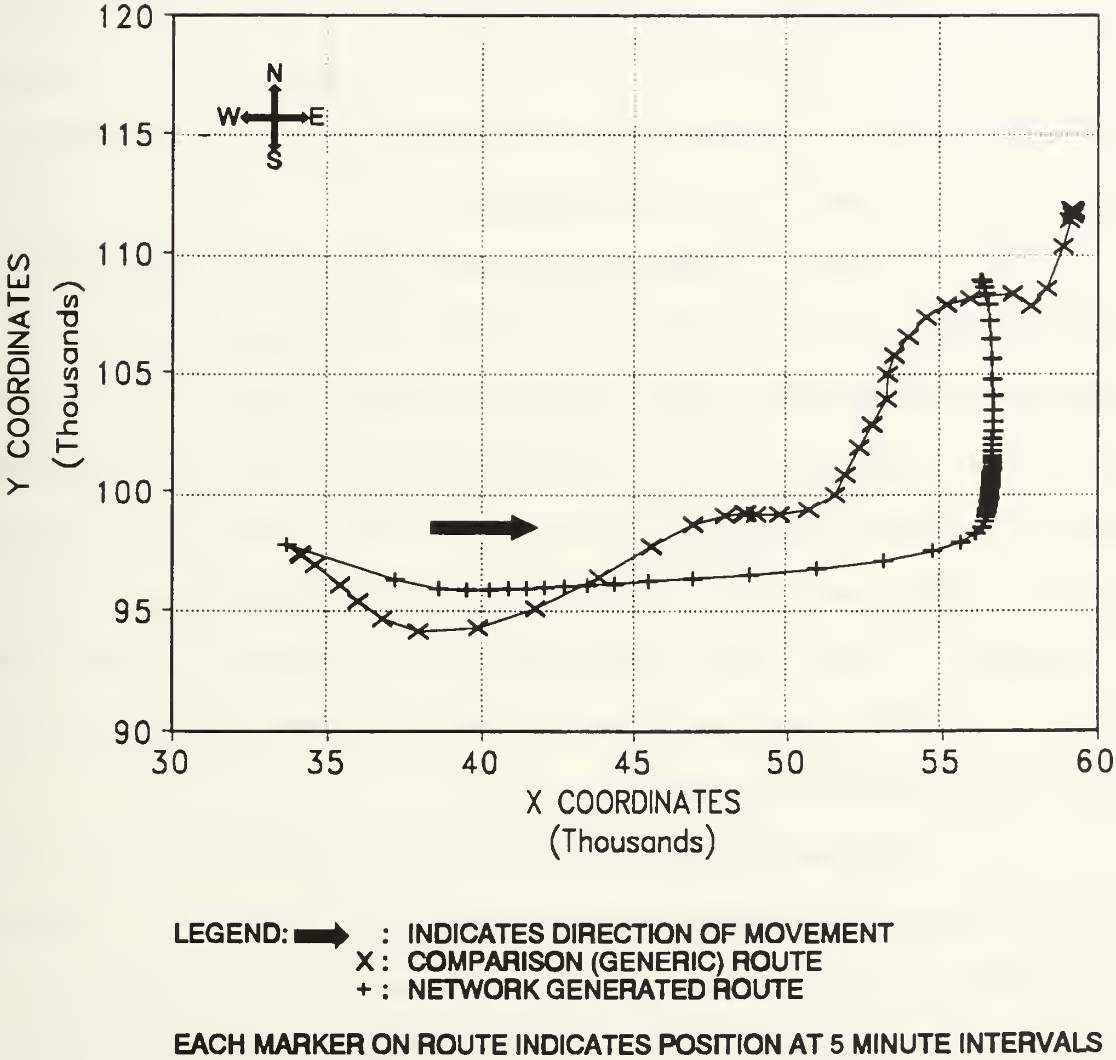


Figure 9. Route Generated by Network with 25 Hidden Neurons

As stated previously, visual comparison eliminated most of the networks from further consideration. Those trained with 8, 10 and 12 hidden neurons merited further consideration.

a. Testing with an Architecture of 8 Hidden Neurons

This network produces a route that is very good visually (Figure 10). In other words, it closely follows the generic tank route's path and ends very near to the average end coordinate. This route follows the path of the generic route more closely than the others.

Closer inspection shows that it contains 30 coordinates compared to the original tank route's 42. This suggests a much more rapid speed of advance than the original tanks. A tank travelling as predicted by this network would reach its destination 60 minutes earlier than the original tanks. This suggests that, although producing a visually acceptable route, this route does not closely follow the original tanks' average speed of advance (the generated tank route is 29 percent faster).

The performance of this network prompted us to try a network with 7 hidden neurons as well. This network (Figure 11) produces a route that is almost identical with that of the network with 8 hidden neurons. It also has 30 positions which suggests the faster speed of advance.

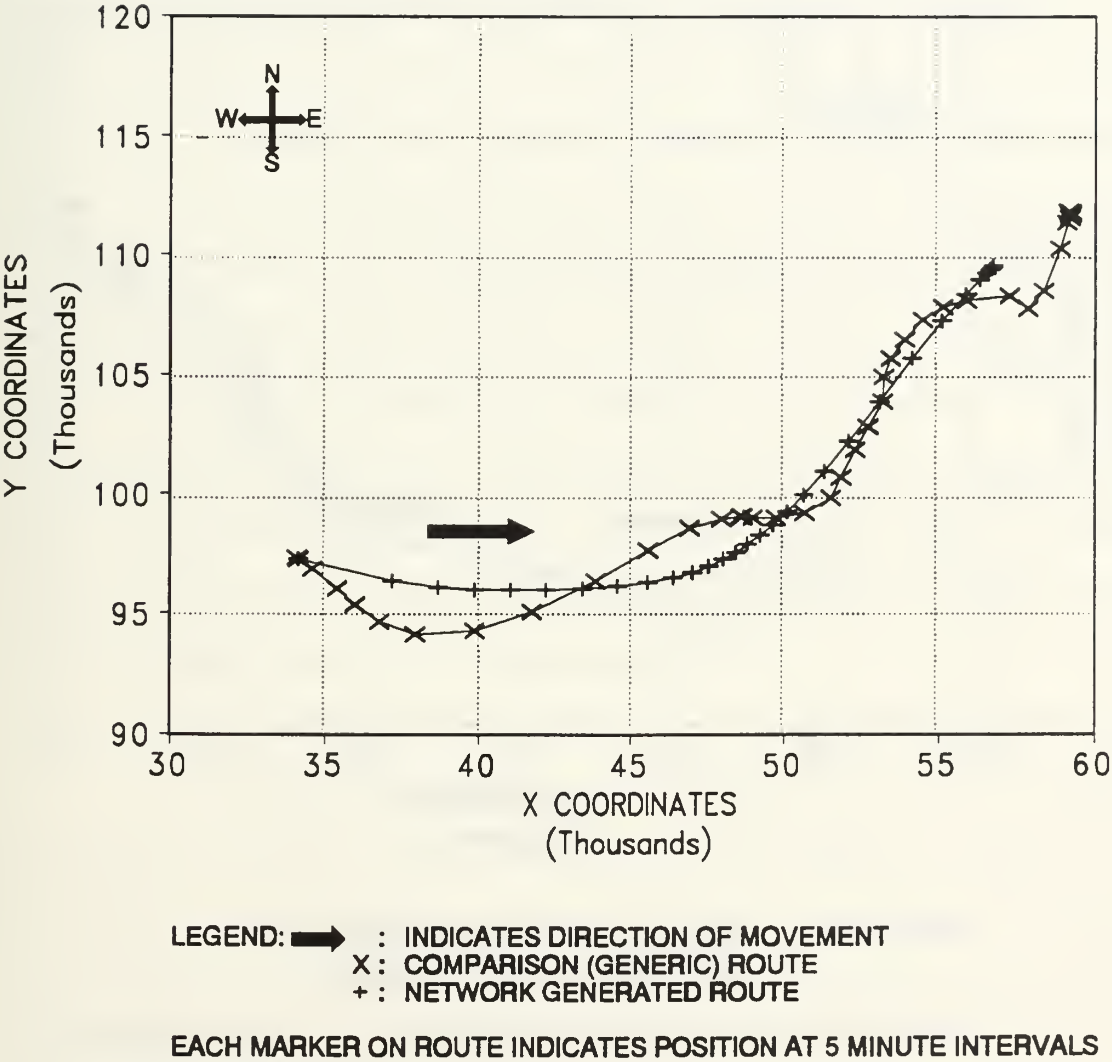


Figure **10**. Route Generated by Network with 8 Hidden Neurons

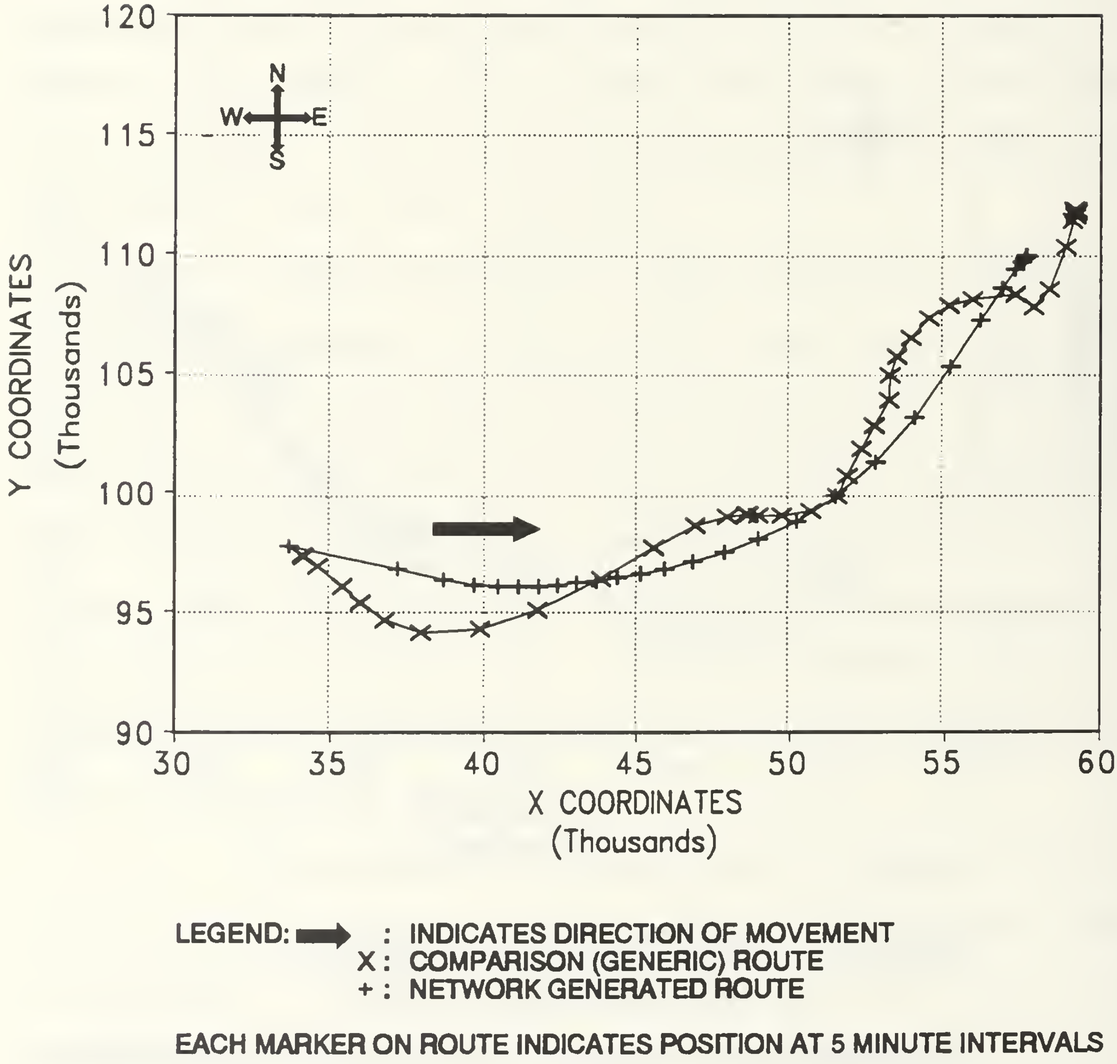


Figure **11**. Route Generated by Network with 7 Hidden Neurons

b. Testing with an Architecture of 10 Hidden Neurons

This network also produces a route that is very good visually (Figure 12). It contains 38 coordinates compared to the original 42 suggesting that this tank would reach the final destination just 20 minutes earlier than the original tanks. Although this is not an exact replication of the actual tanks' speed of advance, it was the nearest of all the networks. It is just 9.7 percent faster than the average.

Since this network generated a very acceptable route, we trained networks with both 9 and 11 hidden neurons to find if either of those produced better routes. The route generated by the network with 9 hidden neurons (Figure 13) is also very good visually, however it contains only 31 coordinates suggesting a much more rapid speed of advance. The route generated by the network with 11 hidden neurons (Figure 14) is only fair visually and has just 21 coordinates. We determined that to be unacceptable.

c. Testing with an Architecture of 12 Hidden Neurons

This network also appeared to be acceptable initially (Figure 15). However, the speed of advance is extremely fast. This route contains just 24 coordinates indicating an average speed of advance 43.9 percent more rapid than the actual tank routes.

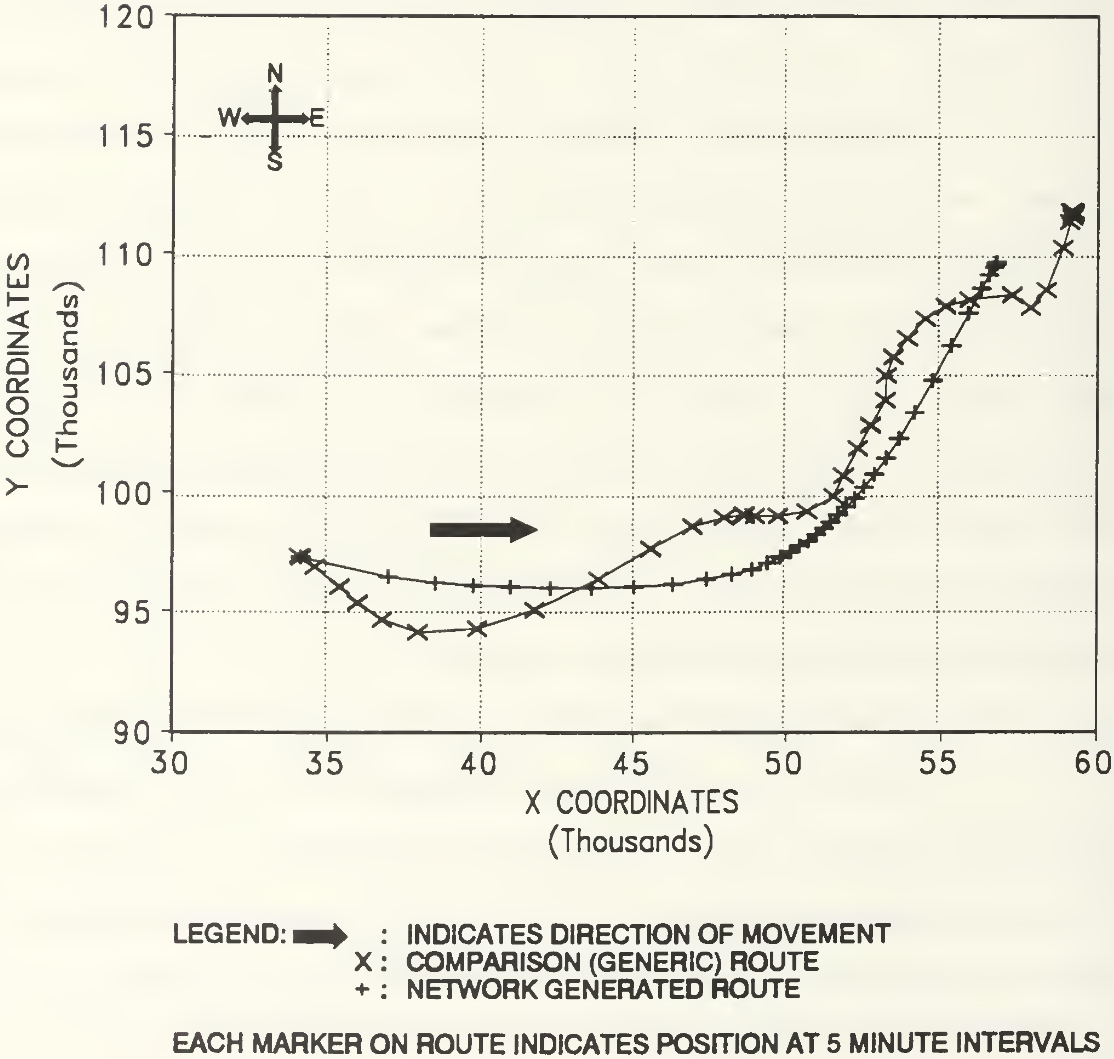


Figure **12**. Route Generated by Network with 10 Hidden Neurons

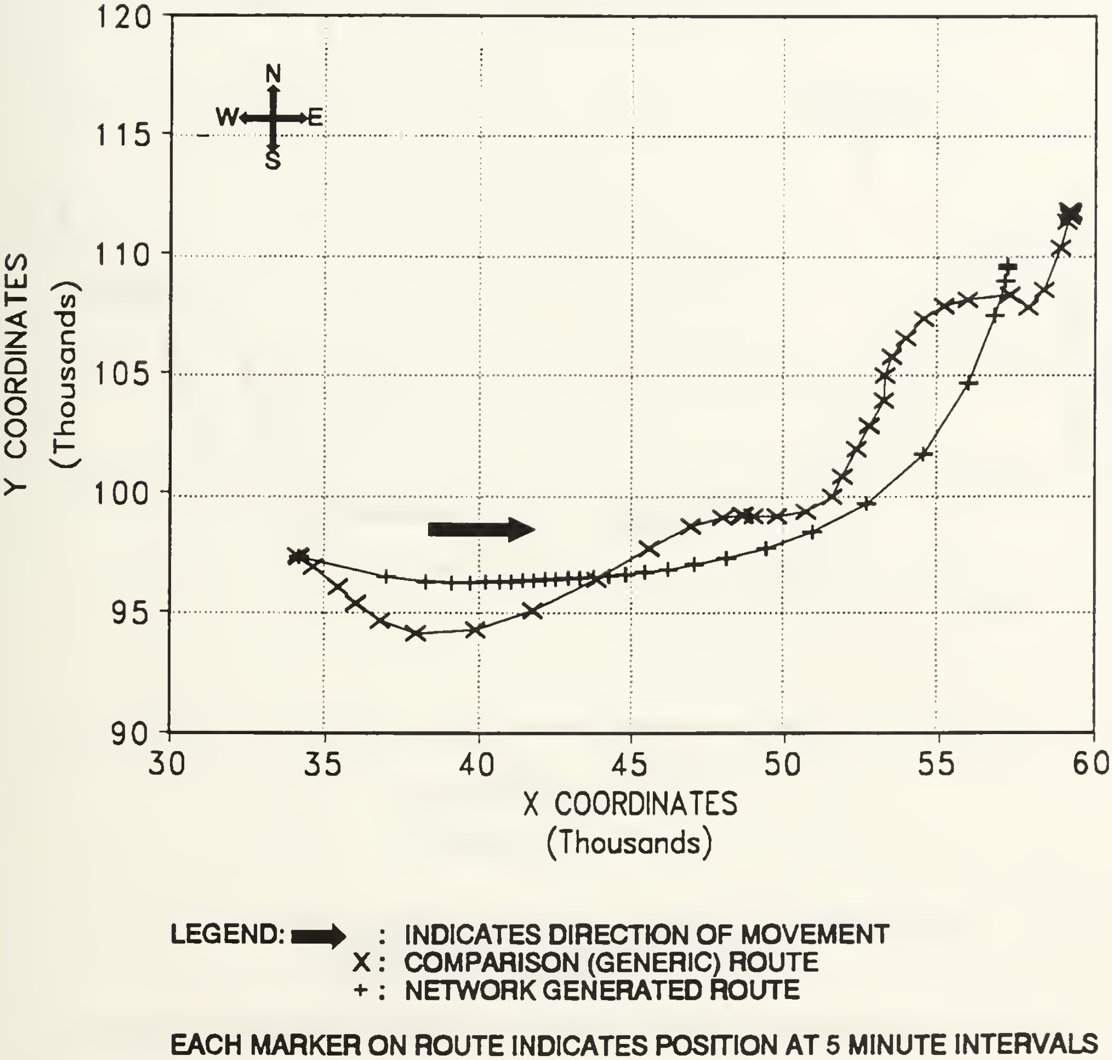


Figure **13**. Route Generated by Network with 9 Hidden Neurons

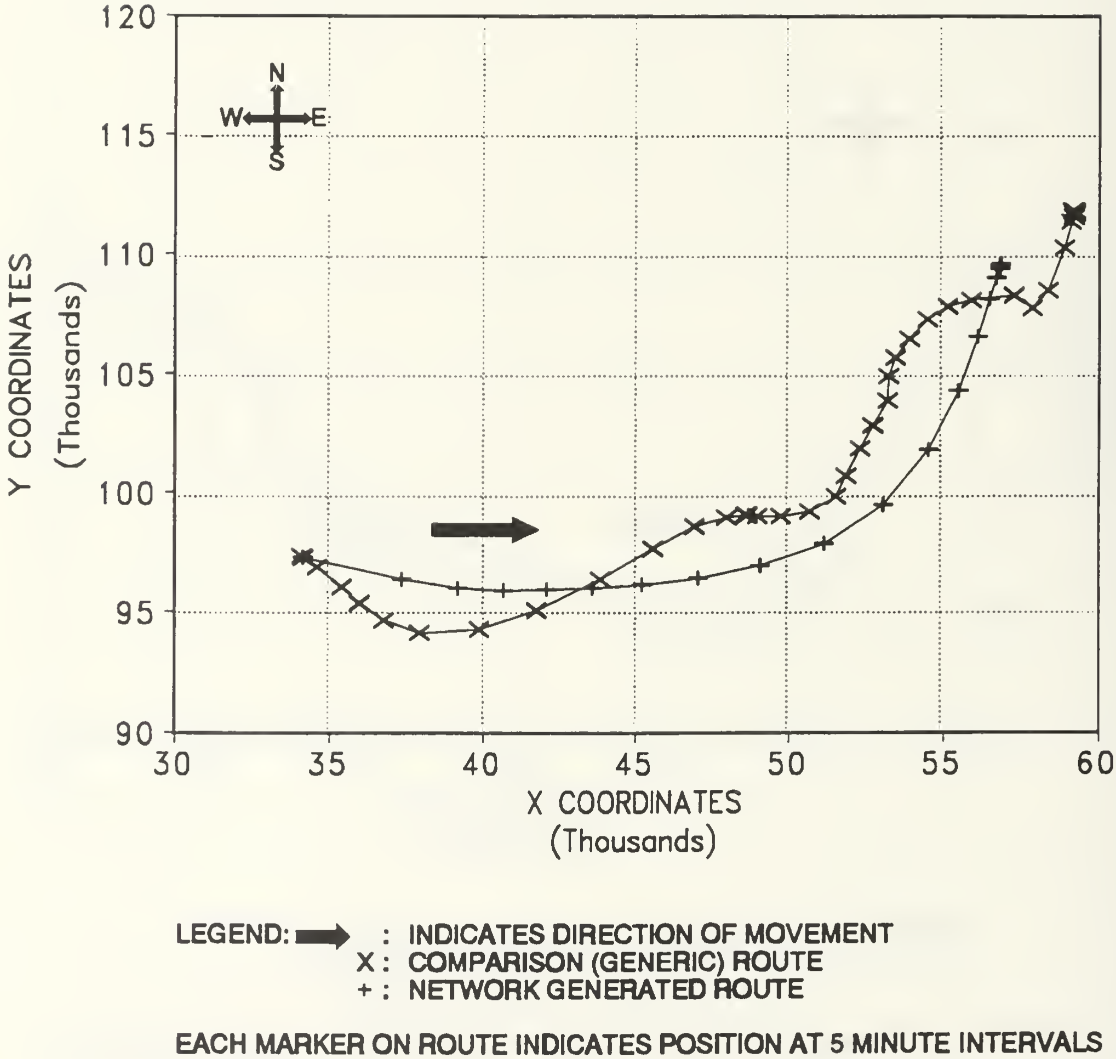
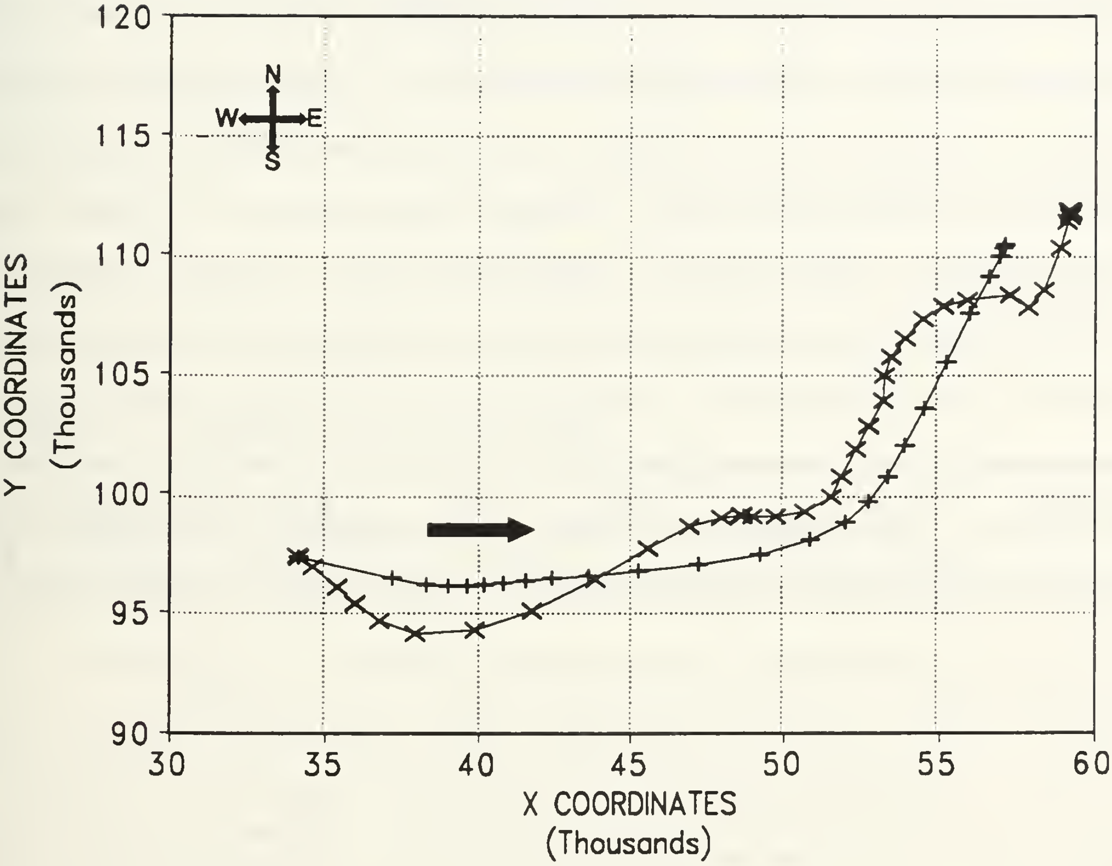


Figure **14**. Route Generated by Network with 11 Hidden Neurons



LEGEND: ➡ : INDICATES DIRECTION OF MOVEMENT
X : COMPARISON (GENERIC) ROUTE
+ : NETWORK GENERATED ROUTE

EACH MARKER ON ROUTE INDICATES POSITION AT 5 MINUTE INTERVALS

Figure **15**. Route Generated by Network with 12 Hidden Neurons

After comparison with the other networks, this network was clearly not the best. We did not train a network with 13 hidden neurons.

d. Discussion

All the networks we trained with various numbers of hidden neurons produce routes except the two mentioned previously (those with 2 and 15 hidden neurons). Yet, most were obviously not good predictors or replicators of the actual routes. For example, those trained with 20 and 25 hidden neurons produced routes that were not very good replications and had an extremely slow average speed of advance (refer to Figures 8 and 9). After comparing all the routes, we narrowed the possibilities to those discussed in the previous three sections.

Initially, we had only planned to compare the routes visually, but we noticed that one of the major differences between routes was the number of coordinates. It became a major evaluation factor since it seems obvious that a tank's average speed is an important behavior. The route produced by the network with 8 hidden neurons followed the generic route's path most closely. Yet, the route produced by the network with 10 hidden neurons also followed the path of the generic route closely and was the closest in average speed of advance. The network with 12 hidden neurons was clearly the inferior of the three.

3. Training Time

Although the BrainMaker documentation indicated that using more hidden neurons will tend to cause the network to train slower, we found that this was not necessarily the case. As we increased the number of hidden neurons from 2 to 10, the training time also increased. However, training time dropped significantly at 15 hidden neurons. The training time for this network was 2 minutes and 48 seconds, but, as explained in the previous section, this network was unable to generate a route. This fact suggests that increasing the hidden neurons will not always increase the training time. Table 2 presents the training time for some selected networks.

TABLE 2. NETWORK TRAINING TIMES

Hidden Neurons	2	8	10	12	15	100
Training Time	7:19	13:53	22:50	7:54	2:48	4:56

Table 2 is a representative sample of the observed training times. Training times did not increase as hidden neurons increased. For example, the network with 100 hidden neurons trained in just 4 minutes and 56 seconds. These times suggest that the number of hidden neurons may not be the factor in training time we expected at all. Of course, the number of hidden neurons may be a significant factor in training time for other problems.

We determined that training time was not a significant evaluation factor. Although the training time for the network with 10 hidden neurons was longer than those of the other networks, it is not sufficiently longer to eliminate it from consideration as the best network.

4. Unexpected Start Positions

We used the three start positions discussed previously (40000 - 105000, 42000 - 110000 and 57000 - 102000) to generate routes with all three of the final networks. Although the network with 12 hidden neurons is clearly not the best of the three, we felt that it would be interesting to include it in this evaluation process for comparison.

We expected the best network to produce routes that clearly led out of the impassable terrain to safe terrain when presented with the first two start positions. We also expected the networks to recognize the third start position in the vicinity of the destination area and to produce a route that leads to the path of the generic route and on to the goal.

a. Testing with and Architecture of 8 Hidden Neurons

Figure 16 shows the routes generated by the network with 8 hidden neurons. Both of the routes originating from the first two start positions lead generally to the safe terrain and on to the goal. The route originating from the third start position quickly moves toward the generic route

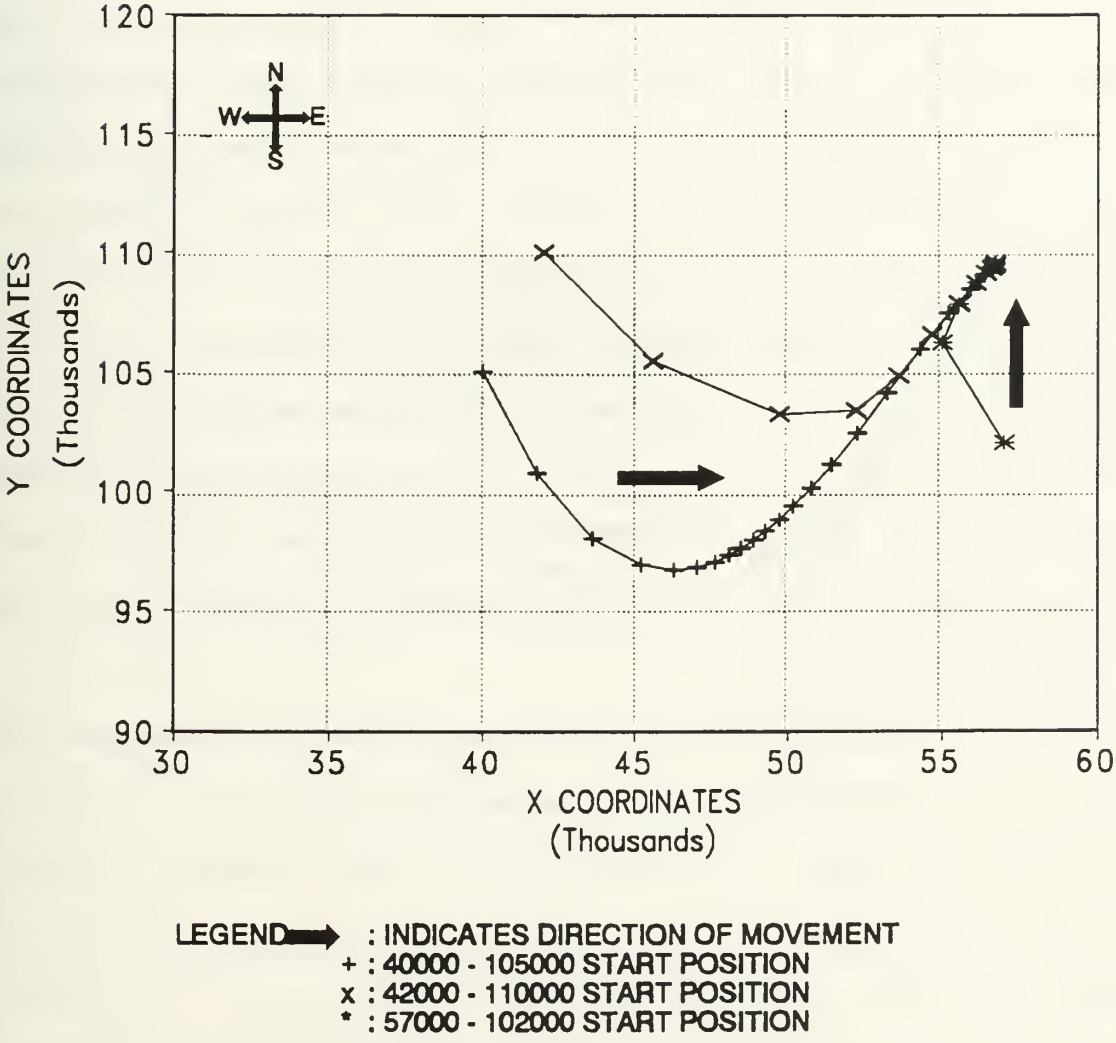


Figure 16. Routes Generated by Network with 8 Hidden Neurons

and on to the goal. We noticed that the rate of advance is very fast from the first two start positions and the routes traverse across the hilly terrain instead of leading more directly to the safe terrain.

b. Testing with an Architecture of 10 Hidden Neurons

These routes (Figure 17) are very interesting. The routes originating at the first two start positions lead very directly to the safe terrain. These routes then appear to follow the path of the route produced from the average start position on to the goal. This network appears to strongly "recognize" the hilly terrain and to try to take a direct route to safe terrain. The route originating from the third start position behaved as expected and behaved very similarly to the route generated by the network with 8 hidden neurons. The speed of advance for all three routes closely follow that of the route this network produced from the average start position.

c. Testing with an Architecture of 12 Hidden Neurons

As expected the routes produced by this network (Figure 18) were the poorest. This network clearly "recognizes" the goal and produced routes from all three start positions that lead very directly to that goal. It clearly does not recognize the hilly terrain and completely ignores it while travelling to the goal. The speed of advance of these routes is extremely fast.

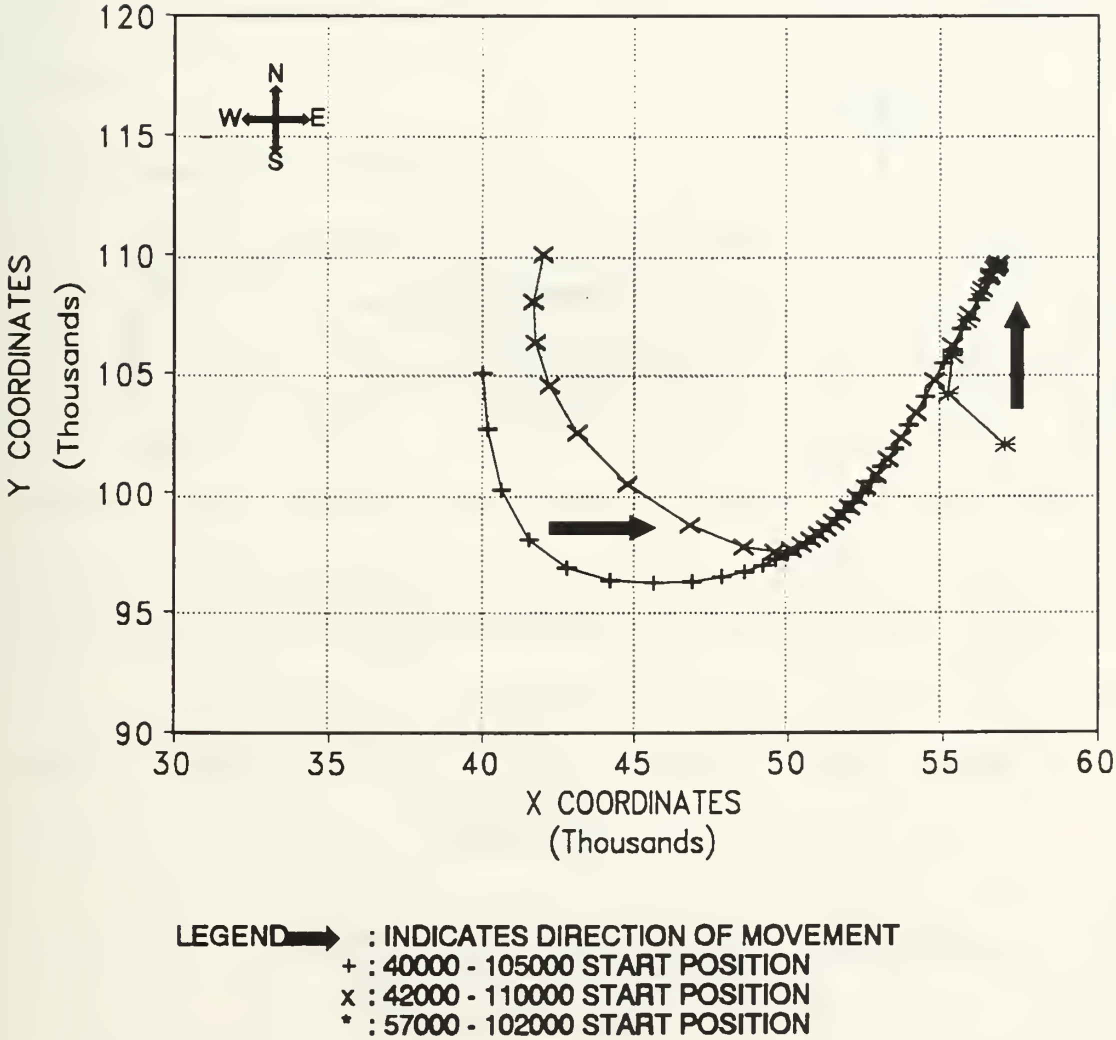


Figure 17. Routes Generated by Network with 10 Hidden Neurons

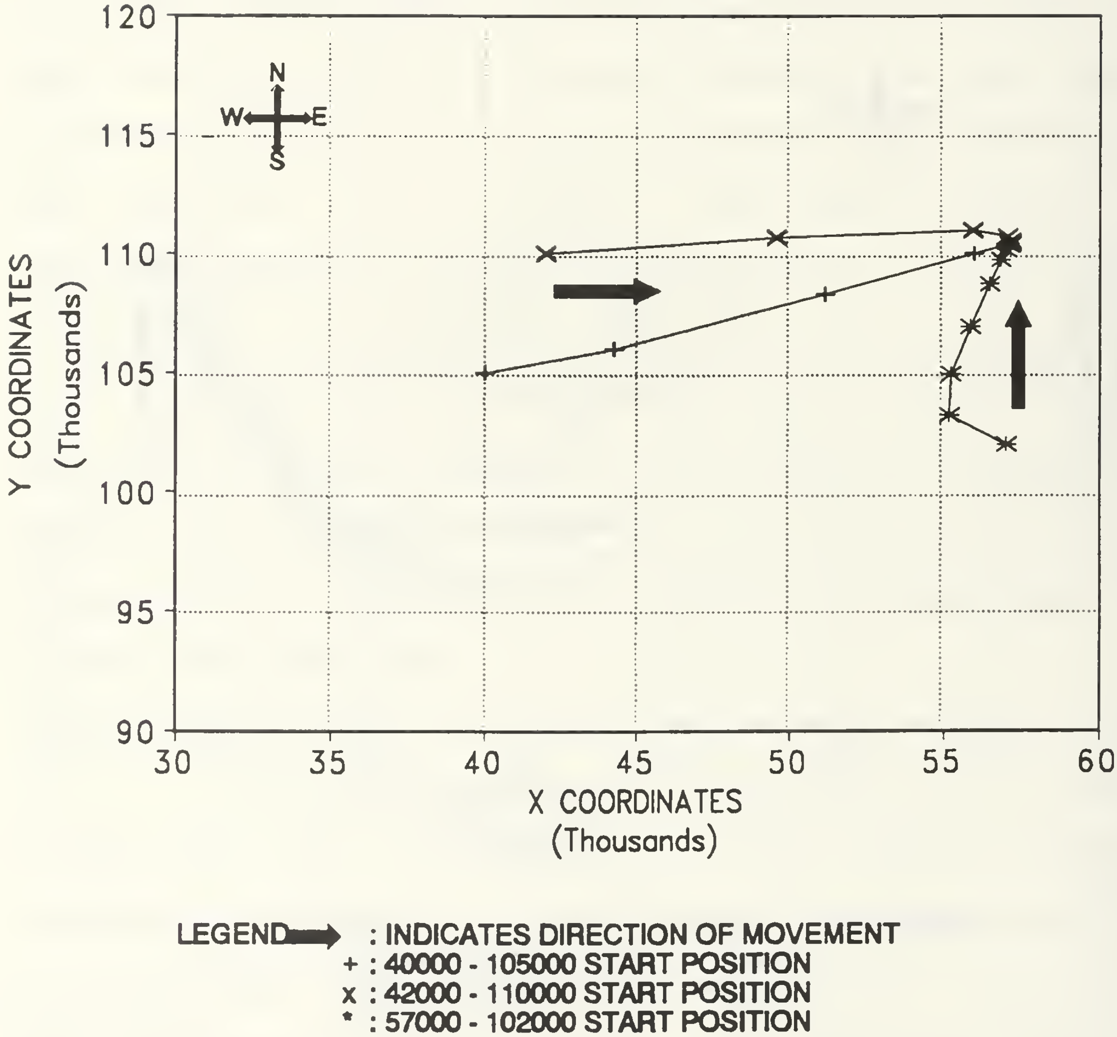


Figure **18**. Routes Generated by Network with 12 Hidden Neurons

d. Discussion

The network with 10 hidden neurons appears to perform best when presented with unexpected start positions. The network with 8 hidden neurons also performs well. However, we believe this route to be inferior because of its rapid speed of advance and because its routes travel through the hilly terrain rather than leading more directly to safe terrain.

C. SUMMARY OF FINDINGS

The networks with 8 and 10 hidden neurons were clearly superior to the network with 12 hidden neurons. Of the former, the network with 8 hidden neurons most closely follows the generic route. However, the network with 10 hidden neurons also follows the generic route very well and most closely replicates the average speed of advance. This network also handles the unexpected start positions best. We believe that the difference in training times is insignificant. These facts lead us to the conclusion that the network with 10 hidden neurons is the best for route determination.

Given the training data for this research, the network architecture required for producing the most accurate routes is clear. The network will consist of 3 layers with the input and output layers both consisting of 2 neurons and the hidden layer consisting of 10 hidden neurons. The network is to be trained to 95 percent.

IV. A PROTOTYPE FOR ROUTE DETERMINATION

A. REQUIREMENTS

As part of the SEAS development, data used for training a network will be presented in a DOS text file for use by this prototype. The data will only contain the information that is relevant; x and y coordinates and the next x and y coordinates for each tank's successful route. The data is changed to represent the coordinates in thousands. For example 55678 will be 55.678. This is because the BrainMaker program is more efficient when dealing with these numbers than with the full numbers. Following is an example of two lines of data from this file:

TABLE 3. EXAMPLE NETWORK TRAINING DATA

X Coordinate	Y Coordinate	Next X Coord.	Next Y Coord.
51.675	100.150	51.863	101.050
51.863	101.050	52.275	102.150

Other requirements are an MS-DOS computer, the BrainMaker program (not provided) and the prototype files.

B. PROTOTYPE ARCHITECTURE

We used a combination of the BrainMaker software, batch files and a program written in Ada to create a prototype of a system that can be used to generate tank routes. Figure 19

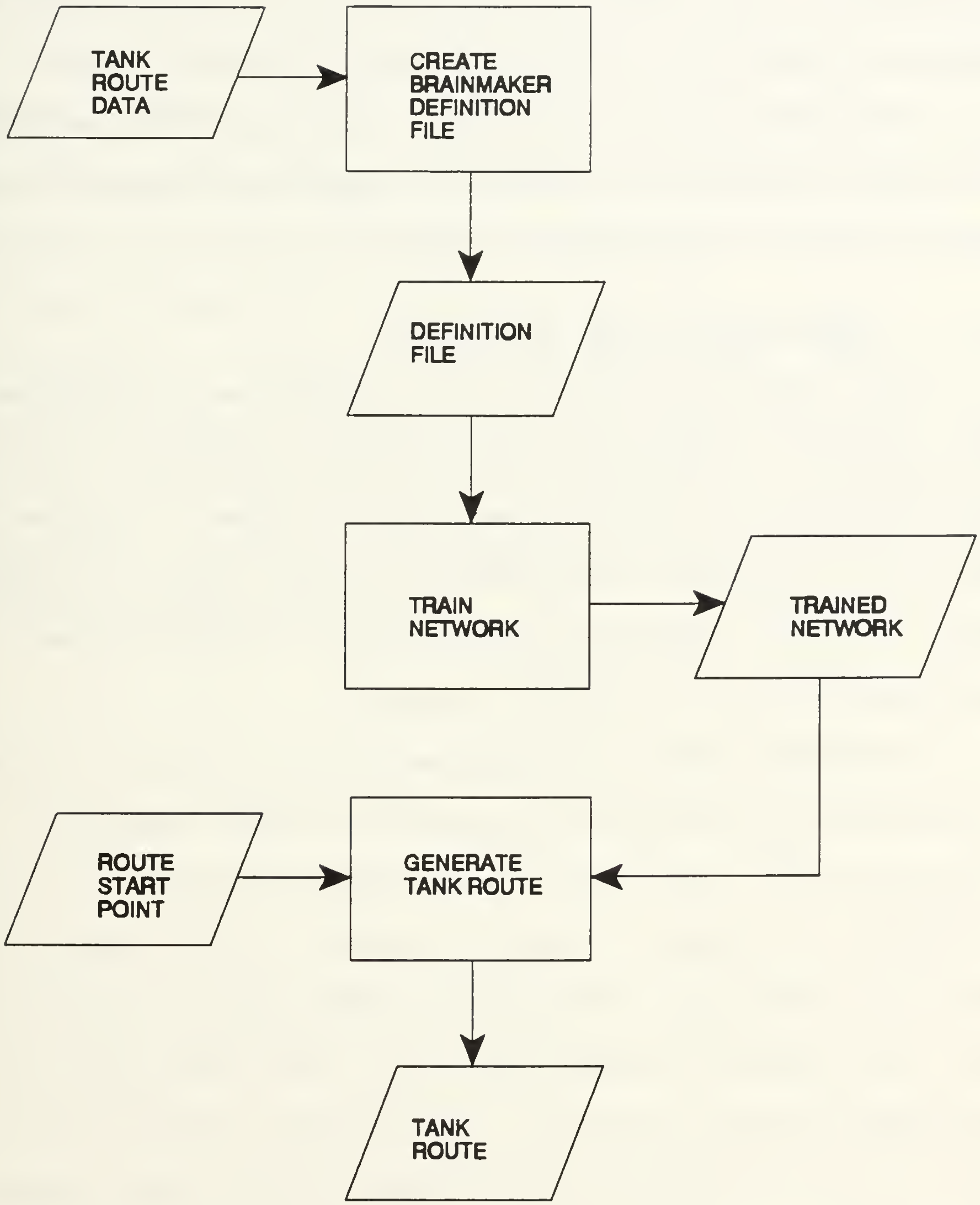


Figure 19. Logical Diagram of Prototype

diagrams the prototype's route generation process. The operating instructions for the prototype are included in Appendix B. The prototype files are available from Professor Bui on request.

We developed the prototype on an MS-DOS 386SX-16MHz Personal Computer. The training and route generation times will vary with the computer hardware.

C. A SAMPLE RUN OF THE PROTOTYPE

Once the data from an actual exercise is gathered and formatted in a DOS text file, the user can begin the process of training a network and generating routes. The user must have the BrainMaker and Netmaker program files, the exercise data file and the prototype batch and program files in the same directory on a MS-DOS computer.

The first step in this process is to create a *BrainMaker Definition file* which will be used to train a network. To do this the user will start the program Netmaker by typing "NETMAKER filename" where filename is the name of the exercise data file. Once the program starts, the user will see the exercise data that will form the basis of the BrainMaker Definition file. The user will classify the first two columns as *"basis"* columns and the next two columns as *"result"* columns (the first two columns represent the "present" x and y coordinates while the next two columns represent the x and y coordinate after 5 minutes). The next

step is to save the definition file as "*brainrts.def.*" The user will then choose the "Go to BrainMaker" option from the menu displayed.

Once BrainMaker is running, the user will set the training percentage to 95 percent and select "train network" from the menu. After the network is trained, the user will save the network as "*brainrts.net.*" The user now has a network trained and ready for use.

To generate routes, the user will start the network generation program by typing "*route*" at the user prompt. The user will be prompted for the start coordinate from which the program will generate a route that will be contained in a DOS text file called "*route.fil.*"

V. CONCLUSION

A. SUMMARY OF FINDINGS

The purpose of this thesis was to (1) search for the best neural network architecture for generating tank routes, and (2) develop a prototype for route generation. Our findings suggested a 3 layer network with 10 hidden neurons that seems to produce the best reproduction of actual routes. The input and output layers will both consist of 2 neurons and the hidden layer will consist of 10 neurons. The network is to be trained to 95 percent. Also, in Chapter IV, we described the architecture of the prototype.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

The findings of this thesis suggest the following recommendations for further research:

- More automation and improvements of the prototype so that it is more user friendly. The prototype presented in this work should be refined to completely automate network training and route generation. The user should be required to do little more than input start positions for routes.

- Testing with more tank battle scenario data. In addition to different battle scenarios, we suggest using various numbers of routes for training and then evaluating the program's effectiveness. We conducted some preliminary tests using as few as 4 routes for training and generated some reasonable route replications.

- Integration with other modules of the SEAS. For example, another module in the SEAS should produce the data file needed by the route determination module for training a network. The routes generated by the route determination module will be used by other modules of the system. The entire SEAS will automate many processes currently performed by human operators.

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APPENDIX A

TANK ROUTE RESEARCH DATA

0	42	42725	94713	42713	94688
5	42	42713	94688	42763	94725
10	42	42763	94725	42713	94700
15	42	42713	94700	42713	94700
20	42	42713	94700	42713	94688
25	42	42713	94688	42713	94700
30	42	42713	94700	42713	94700
35	42	42713	94700	43900	96225
40	42	43900	96225	42713	94700
45	42	42713	94700	43900	96225
50	42	43900	96225	43900	96225
55	42	43900	96225	43900	96225
60	42	43900	96225	44250	98475
65	42	44250	98475	45788	98500
70	42	45788	98500	44250	98475
75	42	44250	98475	48250	100900
80	42	48250	100900	48263	100925
85	42	48263	100925	48250	100900
90	42	48250	100900	48263	100925
95	42	48263	100925	48263	100925
100	42	48263	100925	48263	100925
105	42	48263	100925	51775	100163
110	42	51775	100163	52188	101363
115	42	52188	101363	52638	102363
120	42	52638	102363	53100	103538
125	42	53100	103538	53388	104425
130	42	53388	104425	53363	105475
135	42	53363	105475	53888	106275
140	42	53888	106275	54388	107188
145	42	54388	107188	54975	107675
150	42	54975	107675	55513	107938
155	42	55513	107938	57025	108263
160	42	57025	108263	57888	107813
165	42	57888	107813	58275	107600
170	42	58275	107600	58913	109838
175	42	58913	109838	59338	111250
180	42	59338	111250	59275	112025
185	42	59275	112025	59225	112200
190	42	59225	112200	59213	112200
195	42	59213	112200	59225	112200
200	42	59225	112200	59225	112200
205	42	59225	112200	59225	112200
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5	43	33700	97550	33600	97675

10	43	33600	97675	33575	97763
15	43	33575	97763	33650	97588
20	43	33650	97588	33575	97763
25	43	33575	97763	34325	96738
30	43	34325	96738	34875	96350
35	43	34875	96350	35700	95500
40	43	35700	95500	36575	94588
45	43	36575	94588	38238	93913
50	43	38238	93913	39988	94450
55	43	39988	94450	42163	95163
60	43	42163	95163	44300	96700
65	43	44300	96700	46188	98013
70	43	46188	98013	47363	98725
75	43	47363	98725	48388	99013
80	43	48388	99013	48400	99050
85	43	48400	99050	48550	98988
90	43	48550	98988	49275	98963
95	43	49275	98963	50050	99025
100	43	50050	99025	51138	99288
105	43	51138	99288	51775	100175
110	43	51775	100175	52188	101350
115	43	52188	101350	52613	102250
120	43	52613	102250	53075	103463
125	43	53075	103463	53400	104400
130	43	53400	104400	53350	105450
135	43	53350	105450	53863	106225
140	43	53863	106225	54363	107188
145	43	54363	107188	54963	107650
150	43	54963	107650	55475	107925
155	43	55475	107925	56988	108300
160	43	56988	108300	57875	107850
165	43	57875	107850	58288	107688
170	43	58288	107688	58888	109763
175	43	58888	109763	59275	111150
180	43	59275	111150	59313	111950
185	43	59313	111950	59213	112188
190	43	59213	112188	59213	112200
195	43	59213	112200	59363	112100
200	43	59363	112100	59225	112200
205	43	59225	112200	59213	112188
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20	44	44150	94563	44125	94638
25	44	44125	94638	44075	94663
30	44	44075	94663	42650	94600
35	44	42650	94600	42688	94738
40	44	42688	94738	42325	95050
45	44	42325	95050	42263	94875
50	44	42263	94875	42263	95138

55	44	42263	95138	42350	95238
60	44	42350	95238	42300	95038
65	44	42300	95038	45888	97775
70	44	45888	97775	46963	98475
75	44	46963	98475	48363	99013
80	44	48363	99013	48400	99013
85	44	48400	99013	48463	99013
90	44	48463	99013	49063	98925
95	44	49063	98925	49863	99050
100	44	49863	99050	50963	99200
105	44	50963	99200	51725	100063
110	44	51725	100063	52138	101238
115	44	52138	101238	52575	102200
120	44	52575	102200	53050	103388
125	44	53050	103388	53400	104363
130	44	53400	104363	53338	105425
135	44	53338	105425	53850	106188
140	44	53850	106188	54250	107063
145	44	54250	107063	54888	107563
150	44	54888	107563	55363	107925
155	44	55363	107925	56813	108225
160	44	56813	108225	57825	107925
165	44	57825	107925	58263	107575
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180	44	59288	111175	59363	111800
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75	46	47288	98563	48350	99025
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135	46	53350	105425	53863	106213
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170	50	58700	109050	59175	110700
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5	53	33950	97013	33950	97013
10	53	33950	97013	33950	97013
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105	53	51625	99950	51900	100738
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120	53	52775	102975	53200	103813
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155	53	56075	108150	57538	108338
160	53	57538	108338	58025	107413
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170	53	58575	108638	59075	110413
175	53	59075	110413	59400	111775
180	53	59400	111775	59413	111813
185	53	59413	111813	59400	111800

190	53	59400	111800	59400	111813
195	53	59400	111813	59413	111813
200	53	59413	111813	59413	111813
205	53	59413	111813	59413	111813
0	54	32388	98325	32388	98325
5	54	32388	98325	32388	98325
10	54	32388	98325	32388	98325
15	54	32388	98325	32388	98325
20	54	32388	98325	32388	98325
25	54	32388	98325	34675	96350
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35	54	35488	95613	36175	94838
40	54	36175	94838	36950	94175
45	54	36950	94175	38850	93975
50	54	38850	93975	41238	94588
55	54	41238	94588	43000	95750
60	54	43000	95750	45163	97288
65	54	45163	97288	46613	98513
70	54	46613	98513	48338	99038
75	54	48338	99038	48688	98975
80	54	48688	98975	48800	98963
85	54	48800	98963	49025	98950
90	54	49025	98950	49800	98975
95	54	49800	98975	50725	99150
100	54	50725	99150	51613	99925
105	54	51613	99925	51888	100700
110	54	51888	100700	52375	101750
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70	191	47863	99238	48463	99250
75	191	48463	99250	48838	99163
80	191	48838	99163	48850	99150
85	191	48850	99150	49400	99075
90	191	49400	99075	50088	99138
95	191	50088	99138	51150	99413
100	191	51150	99413	51663	100213
105	191	51663	100213	51863	101138
110	191	51863	101138	52288	102225
115	191	52288	102225	52763	103175
120	191	52763	103175	53288	104288
125	191	53288	104288	53025	105213
130	191	53025	105213	53075	105688
135	191	53075	105688	53313	105838
140	191	53313	105838	54100	106825
145	191	54100	106825	54750	107425
150	191	54750	107425	55113	107838
155	191	55113	107838	56425	108150
160	191	56425	108150	57738	108150
165	191	57738	108150	58388	108100
170	191	58388	108100	59100	110550
175	191	59100	110550	59263	112100
180	191	59263	112100	59163	110863
185	191	59163	110863	59200	112125
190	191	59200	112125	59200	112138
195	191	59200	112138	59200	112125
200	191	59200	112125	59200	112138
205	191	59200	112138	59200	112138
0	192	33675	97600	33688	97588
5	192	33688	97588	33688	97588

10	192	33688	97588	33688	97588
15	192	33688	97588	33700	97463
20	192	33700	97463	34738	96275
25	192	34738	96275	35450	95563
30	192	35450	95563	36188	94825
35	192	36188	94825	37050	94113
40	192	37050	94113	38938	94000
45	192	38938	94000	41338	94625
50	192	41338	94625	43463	96150
55	192	43463	96150	45825	97750
60	192	45825	97750	46913	98813
65	192	46913	98813	47850	99188
70	192	47850	99188	48375	99263
75	192	48375	99263	48788	99163
80	192	48788	99163	48788	99163
85	192	48788	99163	49275	99075
90	192	49275	99075	49963	99125
95	192	49963	99125	51113	99388
100	192	51113	99388	51675	100150
105	192	51675	100150	51863	101050
110	192	51863	101050	52275	102150
115	192	52275	102150	52750	103150
120	192	52750	103150	53275	104238
125	192	53275	104238	53025	105175
130	192	53025	105175	53150	105775
135	192	53150	105775	53850	106313
140	192	53850	106313	54300	107250
145	192	54300	107250	55300	107950
150	192	55300	107950	56550	108213
155	192	56550	108213	57875	108313
160	192	57875	108313	58288	107750
165	192	58288	107750	58725	109250
170	192	58725	109250	59200	110950
175	192	59200	110950	59250	112100
180	192	59250	112100	59238	111075
185	192	59238	111075	59225	112100
190	192	59225	112100	59200	112100
195	192	59200	112100	59225	112100
200	192	59225	112100	59200	112100
205	192	59200	112100	59200	112100

APPENDIX B

PROTOTYPE OPERATING INSTRUCTIONS

REQUIREMENTS:

- BrainMaker Professional software sold by California Scientific Software (not provided with thesis)
- Prototype Diskette (included with thesis)
- MS-DOS based computer with hard drive

GETTING STARTED:

1. Install BrainMaker software on computer hard drive.

2. Copy all prototype diskette files into the BrainMaker directory and change to this directory.

TRAINING A NETWORK

1. Create a BrainMaker Definition file by typing "NETMAKER filename" at the DOS prompt. Filename is the name of the file containing the route data. We included the data used in this thesis (modified as described in Chapter IV, Section A) in a file called data.txt. For example, type "NETMAKER DATA.TXT" to create a definition file from this data.

Within the NetMaker program:

2. Set test file percentage to zero (0).

3. Within the NetMaker program, label the columns, in order, X, Y, NEXTX AND NEXTY.

4. Classify the first two columns as "basis" and the second two columns as "result."

5. Save your definition file as "brainrts.def" and choose the "Go to BrainMaker" option from the menu.

Within the BrainMaker program:

6. Set training percentage to ninety-five (95).

7. Select the "Train Network" option from the menu.

8. After the program trains the network, save the network as "brainrts.net" and exit brainmaker.

GENERATING ROUTES:

1. Start the route generating program by typing "route" at the DOS prompt.

2. Type in the x coordinate of desired start position when prompted. For example, 55.790 if you desire 55790.

3. Type in the y coordinate of desired start position when prompted. For example, 99.45 for 99450.

4. The program will display the start position (for example 55.79 and 99.45) and ask you to verify them. Type "y" and press enter if they are correct and "n" and enter if you wish to change them.

5. When you verify the information is correct, the program will inform you that it is about to generate a route and that you must stop the program by pressing Ctrl-Break when the displayed coordinates start to repeat.

6. The generated route is saved in a file named route.fil.

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